ESTIMATING AVERAGE BASE FLOW AT LOW-FLOW PARTIAL-RECORD STATIONS ON THE SOUTH SHORE OF LONG ISLAND, NEW YORK

by Herbert T. Buxton

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CONTENTS

ILLUSTRATIONS

TABLES

FACTORS FOR CONVERTING INCH-POUND UNITS TO INTERNATIONAL SYSTEM OF UNITS (SI)

For the convenience of readers who may want to use International System of Units (SI), the data may be converted by using the following factors:

Multiply inch-pound units	By	To obtain SI units
inch (in)	25.4	millimeter (mm)
	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
acre	0.4049	hectare (ha)
feet per mile (ft/mi)	0.1894	meter per kilometer (m/km)
cubic feet per second (ft^3/s)	28.32	liter per second (L/s)
	0.02832	cubic meter per second (m^3/s)
million gallons per day (Mgal/d)	0.0438	cubic meter per second (m^3/s)

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ABSTRACT

Streams on Long Island have considerable esthetic, recreational, economic, and ecologic value. In relatively undeveloped areas, streams derive as much as 95 percent of the total flow from ground-water seepage (base flow). This report describes the application of a technique for estimating the average base flow of a stream that has only partial discharge records by relating the measured base flow of that stream to concurrent flows of a nearby stream having a continuous record. The stream's average base flow at the partial-record station is estimated from the average measured base flow for a given period at the continuous-record station and a regression equation.

Data used in this analysis were from 1968-75, a period near hydrologic equilibrium on Long Island. The average base flow for this period was estimated for 20 streams that have partial-record stations. Analyses were considered acceptable if the regression coefficient was 85 percent significant or greater and the standard error of estimate was 0.5 (log units) or less.

Average base flow of the nine streams that have a continuous record totaled 90 ft^3/s (cubic feet per second). The predicted average base flow for the 20 streams with only a partial record was 73 ft^3/s, with a 95-percent confidence interval of 63 to 84 ft^3/s. The total of 163 ft^3/s for all 29 streams represents most of the ground-water seepage to streams in the area and equals more than 25 percent of the area's recharge from precipitation.

Results indicate that the method for estimating long-term average base flow is reliable for areas such as Long Island, where streams consist mostly of base flow and are geomorphically and hydrologically similar.

INTRODUCTION

Streams are a major component of Long Island's hydrologic system and play an important environmental and economic role. Many streams and ponds provide esthetic, ecologic, and recreational benefits, and several are the focal point of local parks, where they are used for boating and fishing and provide wildlife habitats. Two streams support freshwater fish hatcheries, and many contain spawning grounds for certain saltwater species. In addition, the continuous discharge of freshwater to the brackish bays surrounding Long Island (fig. 1), both as streamflow and as subsea discharge, maintains the delicate balance of salinity needed for the island's large shellfish industry. Thus, a primary concern in this densely populated area is the protection of these streams from contamination and depletion.

Urbanization has had a marked effect on the hydrologic conditions in western Long Island (Buxton and others, 1981). Reduced ground-water recharge, which results from increases in impervious land surface and from the installation of storm sewers and sanitary sewers, has caused declines in ground-water levels, which, in turn, have reduced the base flow of streams. The hydrologic effects of urbanization have been observed in Nassau County and, to a lesser degree, in western Suffolk County (Sulam, 1979; Pluhowski and Spinello, 1978; Garber and Sulam, 1976; and Franke, 1968). Recent data indicate, however, that the hydrologic effects of urbanization are increasing eastward (Simmons and Reynolds, 1982, Prince, 1981, and Pluhowski and Spinello, 1978).

The U.S. Geological Survey, in cooperation with Nassau County Department of Public Works and Suffolk County Department of Health Services, has investigated the effects of proposed sewering in Sewage Disposal District 3 (SDD-3) in southern Nassau County and Southwest Sewer District (SWSD) in southwest Suffolk County (fig. 2) on the ground-water and surface-water systems. Results indicate that the proposed sewering will decrease ground-water levels and ground-water seepage to streams (base flow) and surrounding bays (Reilly and others, 1983, Buxton and Reilly, 1985, and Reilly and Buxton, 1985).

Estimation of the average base flow of streams in the area is an important step in defining the role of streams as a major discharge boundary of the Long Island ground-water system. The resulting information is needed to define initial conditions for future quantitative studies of the effects of sewers on the hydrologic system of Long Island.

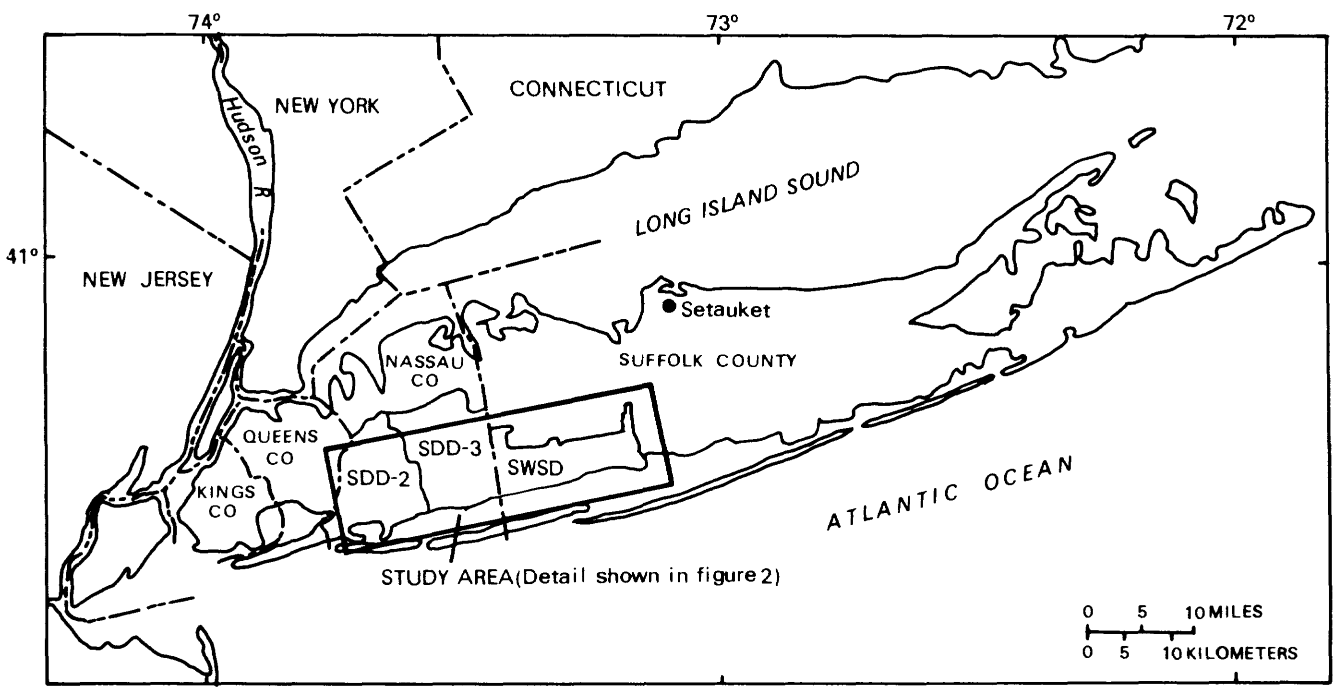


Figure 1.--Location of study area on Long Island.

Purpose and Scope

This report presents results of a small part of a long-term study to evaluate the effects of sanitary sewers on Long Island. It describes a statistical technique (Riggs, 1972) that can be used to estimate average base flow at low-flow partial-record stations on Long Island, and defines the average ground-water seepage (base flow) to each of the 29 major streams in southern Nassau and southwest Suffolk County during 1968-75.

Location of Study Area

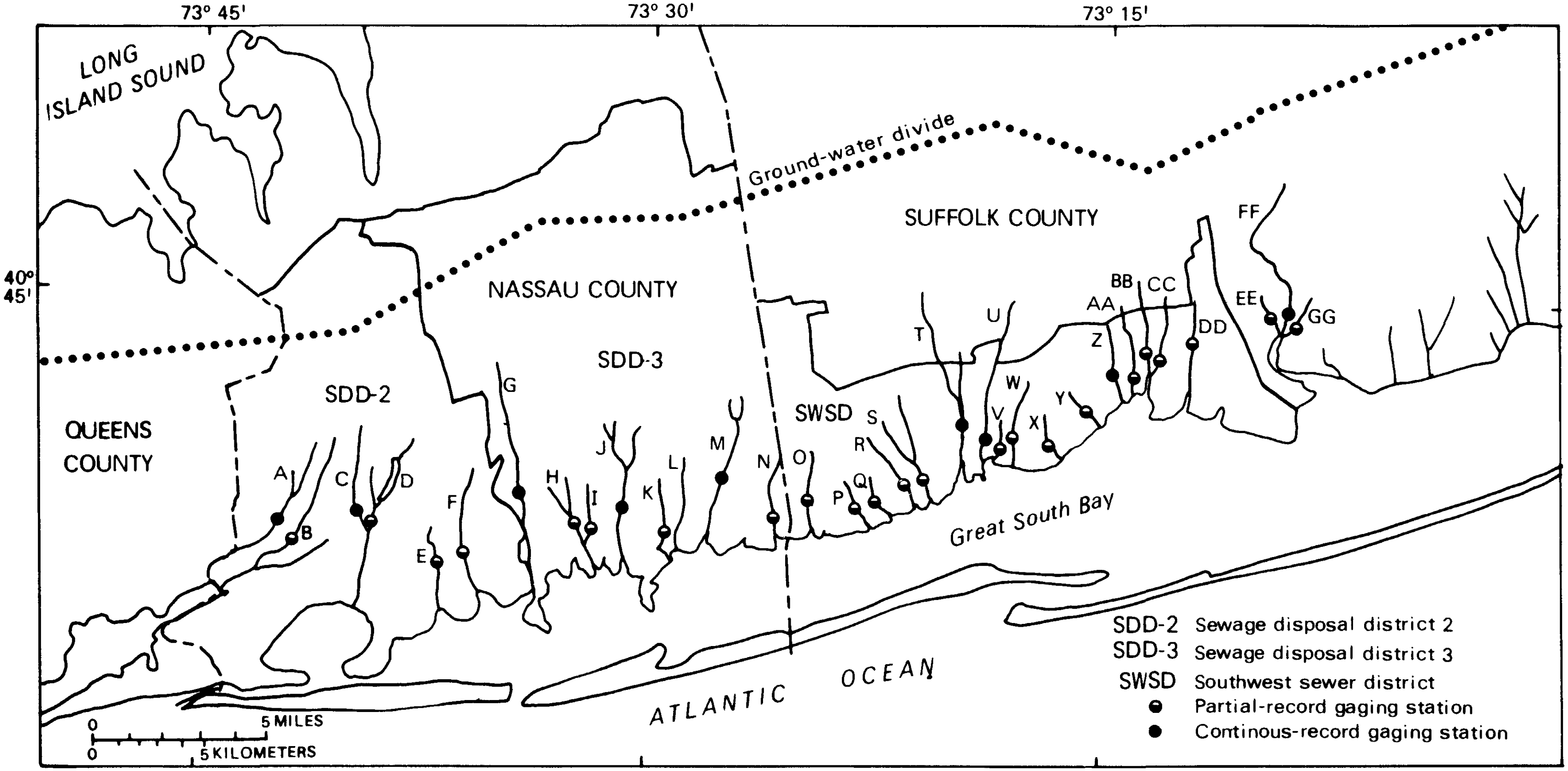
The area studied extends from the Queens-Nassau County border near Valley Stream to Rattlesnake Brook, just east of Connetquot River in central Suffolk County, and north to the regional ground-water divide (fig. 2). It includes the two aforementioned sewer districts. Only streams within or very near to the sewer districts were considered in this investigation because they will be most severely affected by sewering. Names and locations of streams studied are shown in figure 2.

HYDROLOGIC SETTING

The ground-water flow system on Long Island involves interaction between ground water and surface water near land surface. Long Island's fresh water is stored mostly in the unconsolidated geologic deposits below the water table, which are collectively referred to as the ground-water reservoir. Fresh water also is present in streams and ponds, but the water in these surface systems forms only a small percentage of the total fresh water.

Precipitation is the only natural source of fresh water to the Long Island hydrologic system; annual precipitation averages 44 to 46 inches. Almost half (21 to 22 inches) is lost to evapotranspiration, and about 0.5 inches is lost to streams as overland runoff; the remaining 23 to 24 inches infiltrates to the water table and recharges the ground-water reservoir (Franke and McClymonds, 1972, p. 20, and Cohen, Franke and Foxworthy, 1968, p. 58-59). In undisturbed areas, overland runoff is only a small component of the hydrologic budget because the island's coarse and highly permeable surficial deposits enable rapid infiltration. Pluhowski and Spinello (1978, p. 264) estimate that only the precipitation that falls directly into streams and ponds or within a few yards of them becomes direct runoff.

Drainage areas of streams in the study area range from a few square miles to the 38-mi^2 basin of Massapequa Creek (fig. 2). Much of the basin and channel morphology is a result of the late Pleistocene glaciations, when these streams carried large quantities of meltwater to the sea. As a result, their present peak discharges are of short duration and relatively low magnitude.



Base from U.S. Geological Survey
State base map, 1:500,000, 1974

Figure 2.--Location of streams studied: A, Valley Stream; B, Motts Creek; C, Pines Brook; D, South Pond; E, Parsonage Creek; F, Milburn Creek; G, East Meadow Brook; H, Cedar Swamp Creek; I, Newbridge Creek; J, Bellmore Creek; K, Seamans Creek; L, Seaford Creek; M, Massapequa Creek; N, Carman Creek; O, Amityville Creek; P, Great Neck Creek; Q, Strongs Creek; R, Neguntatogue Creek; S, Santapogue Creek; T, Carlls River; U, Sampawams Creek; V, Skookwams Creek; W, Willets Creek; X, Trues Creek; Y, Cascade Lakes; Z, Penataquit Creek; AA, Awixa Creek; BB, Orowoc Creek; CC, Pardees Pond Outlet; DD Champlin Creek; EE, West Brook; FF, Connetquot Creek; GG, Rattlesnake Brook.

The discharge of streams during dry weather is maintained by ground-water seepage. Where the water table is high enough to intersect stream channels, ground water seeps into the channels and flows to the sea. Most of the annual streamflow consists of ground-water seepage. Pluhowski and Kantrowitz (1964, p. 35) estimated that before man's influence, 95 percent of Long Island's total annual streamflow was derived from ground-water seepage. Of the total freshwater discharged from the Long Island ground-water reservoir, about 40 percent is in the form of seepage to streams. (The rest is subsea ground-water discharge or is consumed by man.)

Several reports describe in greater detail the interaction of ground-water and surface-water systems on Long Island, including those by Prince (1980) and Franke and Cohen (1972).

DESCRIPTION OF EQUILIBRIUM HYDROLOGIC CONDITION

Although hydrologic conditions in recent decades show a continued and increasing response to urbanization, 1968-75 represents a hiatus in this trend. During 1968-75, net ground-water use (net indicates that the water used was not returned to the ground-water system) on Long Island remained virtually constant. Net pumpage in eastern Queens County, which in preceding years had shown an extensive effect on ground-water levels, did not increase (Buxton and others, 1981). Net pumpage in Nassau and Suffolk Counties also was relatively stable because few sanitary sewer systems were installed during this period. (Sewers are installed to prevent wastewater from domestic waste-disposal systems from contaminating the shallow ground-water system, but in so doing, they divert to the ocean a significant volume of water that would have recharged the ground-water reservoir.) By 1968, the ground-water system had adjusted to conditions resulting from the sewers that had been installed in Nassau County SDD-2 in the late 1950's (Sulam, 1979), and no additional sewering was implemented in Nassau County SDD-3 until the mid-1970's.

Precipitation by 1968 had returned to normal after 4 years of drought in the early 1960's (Cohen, Franke, and McClymonds, 1969); average precipitation at Setauket, N.Y. (fig. 1), during 1968-75 was 46.3 inches, which was comparable to the long-term average of 44.8 inches.

Although hydrologic conditions by 1968 had probably not recovered entirely from the early 1960's drought, they had nevertheless adjusted to the current stresses of urbanization and had, in fact, approached a new equilibrium characterized by near-average recharge conditions.

An equilibrium period was selected for application of the discharge-estimation technique described herein to ensure that the mathematical relationships developed among adjacent streams could be assumed constant for discharge data collected throughout the period.

ESTIMATING AVERAGE BASE FLOW

Simultaneous discharges of adjacent streams on Long Island have been related on graphs (D. E. Vaupel, U.S. Geological Survey, written commun., 1979). To refine these relationships, a least-squares linear-regression analysis was applied to available streamflow data to predict the average base flow of streams having only a partial discharge record for 1968-75. Although the least-squares method has been somewhat inadequate in prediction of low-flow statistics, a discussion by Thomas (1982) on several fitting techniques indicates that the least-squares method is reliable for prediction of mean base-flow values.

The regression analysis established a relationship between the instantaneous discharge at a partial-record station and the concurrent daily mean discharge at a nearby continuous-record station during periods of base flow. Because data were collected during periods of base flow, it can be assumed that daily mean discharge is a close approximation of the concurrent instantaneous discharge and that the data were not influenced by the effects of overland runoff nor the associated bank storage. All discharge data were screened (1) by comparison with precipitation records to ensure that the effects of direct runoff were not involved in the analyses; (2) by elimination of data affected by local phenomena such as dewatering for construction or readjustment of lake spillways; and (3) by comparison with tide tables to eliminate the effects of abnormally high tides.

Streamflow Data

The study area contains 29 major streams, all of which have discharge records for 1968-75. Nine of the larger streams have a continuous record; the remaining 20 have a partial record consisting of intermittent measurements taken during periods of base flow. All gages are installed as far downstream as possible above the limit of normal tidal effects. Stream locations are shown in figure 2; locations of continuous-record stations are listed in table 1, and locations of partial-record stations are listed in table 2.

The average base flow (average of daily means) of the nine streams having a continuous record was calculated by Reynolds (1982), who applied a technique of base-flow-separation analysis to the continuous-streamflow hydrograph. These values are given in table 4 (p. 16). The number of base-flow measurements taken at each partial-record station during 1968-75 ranged from 4 to 42. These data and daily mean discharges at the continuous-record stations are published annually by the U.S. Geological Survey (1968-75).

Transformation of Data

The regressions were performed on log-transformed data for two reasons. The first is that log transformation tends to normalize the distribution of the dependent and independent variables. Inherent in the measurement of stream base flow is the abundance of data in the lower discharge range and sparse data for higher base-flow discharges; the resultant skewed distribution is evident in discharge histograms for Carlls River and Sampawams Creek (fig. 3). The logarithmic transformations achieve distributions much closer to normal and, in addition, cause residuals about the regression line to be more normally distributed.

Table 1.--Location of continuous gaging stations.

[Stream locations are shown in fig. 2]

Station no.	Stream	Location[1]	Latitude-Longitude
01311500	Valley Stream	On right bank, 40 ft (13 m) upstream from West Valley Stream Blvd., at Valley Stream.	40°39'49" 73°42'18"
01311000	Pines Brook	On left bank, 100 ft (31 m) downstream from Lakeview Ave. and southern boundary of Malverne.	40°40'01" 73°39'35"
01310500	East Meadow Brook	On right bank in Freeport, 24 ft (7.3 m) upstream from bridge on Hempstead-Babylon Tpke., and 400 ft (122 m) west of Meadowbrook Parkway.	40°39'56" 73°34'13"
01310000	Bellmore Creek	On right bank 40 ft (13 m) east of intersection of Valentine Place and Mill Road, in Bellmore, 0.5 mi (0.8 km) north of Sunrise Highway, and 0.5 mi (0.8 km) northwest of Wantagh.	40°40'43" 73°30'58"
01309500	Massapequa Creek	On left bank 350 ft (107 m) west of Garfield Street at Lake Shore Drive, Massapequa, 0.2 mi (0.3 km) north of Massapequa Park and 3,000 ft (914 km) upstream from Clark Ave. and Head of Massapequa Pond of Brooklyn water-supply system.	40°41'20" 73°27'19"
01308500	Carlls River	On left bank in Babylon, 130 ft (40 m) downstream from outlet of Southards Pond and 0.9 mile (1.4 km) upstream from mouth.	40°42'31" 73°19'44"
01308000	Sampawams Creek	On left bank at upstream side of John Street Bridge in Babylon, 180 ft (55 m) downstream from L.I.R.R. and 3,000 ft (914 m) upstream from mouth.	40°42'15" 73°18'52"
01307500	Penataquit Creek	On right bank just upstream from Union Ave. in Bayshore, 4,500 ft (1,372 m) upstream from mouth.	40°43'37" 73°14'41"
01306500	Connetquot River	On left bank just downstream from highway (SR27) bridge, 1 mi (1.6 km) west of Oakdale.	40°44'51" 73°09'03"

[1] right bank is the right side of stream when facing downstream.

Table 2.--Location of low-flow partial-record gaging stations.

[Stream locations are shown in fig. 2]

Station no.	Stream	Location	Latitude-Longitude
01311200	Motts Creek	50 ft (15 m) downstream from bridge on Rosedale Rd., 1 mi (2 km) southwest of Valley Stream.	40°39'01" 73°42'45"
01310800	South Pond Outlet	At bridge on Lakeview Ave., 0.75 mi (1.21 km) north of Rockville Centre.	40°40'00" 73°39'08"
01310700	Parsonage Creek	20 ft (6 m) downstream from bridge on Foxhurst Road, at Baldwin.	40°38'48" 73°36'59"
01310600	Milburn Creek	50 ft (15 m) downstream from bridge on State Highway 27A, 0.5 mi (0.8 km) east of Baldwin.	40°39'04" 73°36'13"
01310200	Cedar Swamp Creek	At bridge on State Highway 27A, in Merrick, 2.5 mi (4.0 km) east of Freeport.	40°39'39" 73°32'24"
01310100	Newbridge Creek	Downstream from bridge on Merrick Road in Merrick.	40°39'42" 73°32'02"
01309800	Seamans Creek	At culvert on State Highway 27A, 0.2 mi (0.3 km) west of Seaford.	40°39'56" 73°29'37"
01309400	Carman Creek	At bridge on State Highway 27A, 0.75 mi (1.21 km) west of Amityville.	40°40'09" 73°26'02"
01309350	Amityville Creek	100 ft (30 m) upstream from State Highway 27A, at Amityville.	40°40'13" 73°24'51"
01309300	Great Neck Creek	30 ft (9 m) upstream from State Highway 27A, in Copiague.	40°40'12" 73°23'21"
01309250	Strongs Creek	30 ft (9 m) upstream from State Highway 27A, in Lindenhurst.	40°40'22" 73°22'40"
01309200	Neguntatogue Creek	20 ft (6 m) upstream from State Highway 27A in Lindenhurst.	40°40'47" 73°21'40"
01309100	Santapogue Creek	At culvert on State Highway 27A, 0.5 mi (0.8 km) downstream from gaging station and 1 mi (1.6 km) east of Lindenhurst.	40°41'02" 73°21'06"
01307600	Cascade Lakes Outlet	At culvert on Montauk Highway in Brightwaters.	40°42'40" 73°15'38"
01307400	Awixa Creek	At culvert on State Highway 27A, 0.75 mi (1.21 km) west of Islip.	40°43'39" 73°13'51"
01307300	Pardees Pond Outlet	At culvert on State Highway 27A, at Islip.	40°43'40" 73°13'16"
01307200	Orowoc Creek	At culvert on Moffitt Blvd., 0.5 mi (0.8 km) west of Islip.	40°44'00" 73°13'32"
01307000	Champlin Creek	At LIRR bridge, 220 ft (67 m) downstream from Moffitt Blvd. at Islip.	40°44'13" 73°12'08"
01306800	West Brook	At Pond Outlet, 80 ft (24 m) upstream from State Highway 27A, 1.75mi north of Great River.	40°44'42" 73°09'25"
01306700	Rattlesnake Brook	50 ft downstream from State Highway 27, 1.5 mi (2.4 km) northwest of Oakdale.	40°44'52" 73°08'45"

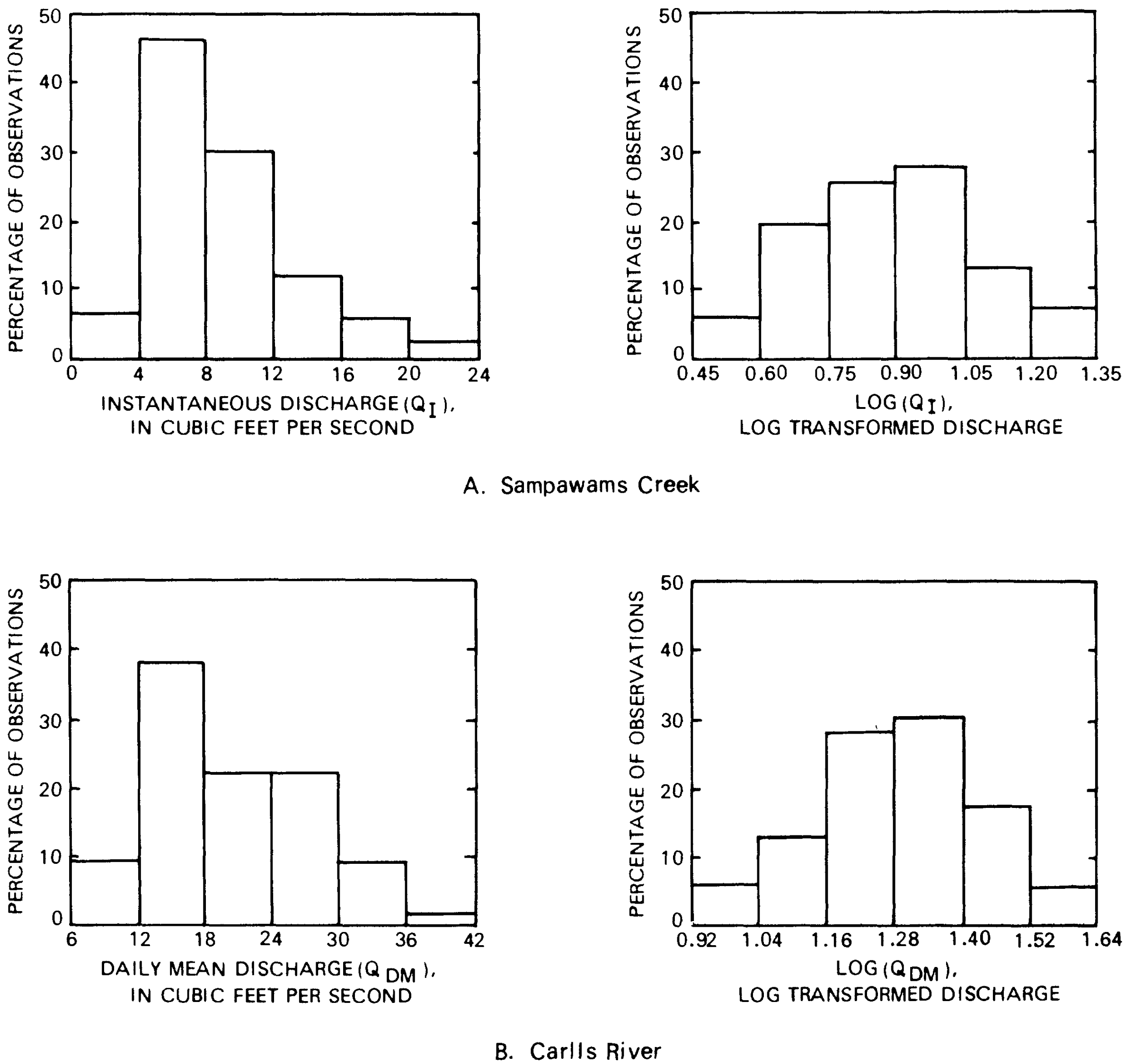


Figure 3.--Frequency histograms for two adjacent continuous-record streams: A. Base flow measured at Sampawams Creek, plotted directly (left) and log-transformed (right). B. Concurrent daily mean discharge at Carlls River, plotted directly (left) and log-transformed (right).

The second reason for log transformation is that it makes the variance of deviations of the dependent variable about the regression line more uniform (homoscedastic residuals). Stated more simply, scatter about the regression line must be approximately uniform throughout the range of data. Figure 4A is a plot of concurrent discharge data for Carlls River and Sampawams Creek in which the scatter about the regression line increases at higher discharges. Figure 4B is a plot of the logarithm of the concurrent discharge data; here the variance of deviations about the line of "best fit" is more uniform.

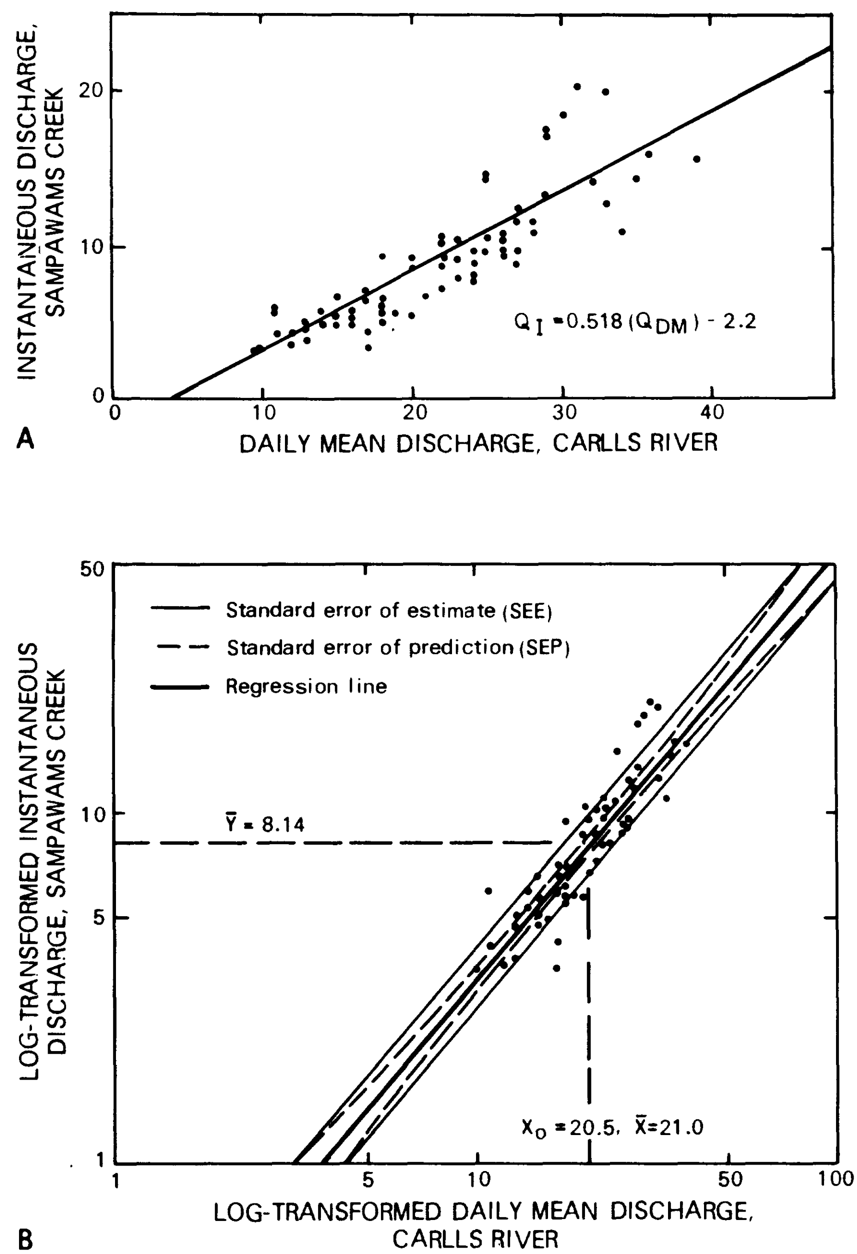


Figure 4.--Regression plots of concurrent base flow of two adjacent streams: A. Discharge data plotted directly. B. Log-transformed data. ($\bar{X}$ is the average of the daily mean discharges of Carlls River for the measurements plotted. X_o is the average base flow of Carlls River as calculated by a hydrograph-separation technique. X_o is used to estimate the average base flow of Sampawams Creek. $\bar{Y}$ is the average base flow of Sampawams Creek.)

Regression Equation and Estimation

The least-squares regression analysis provides the "best fit" of the data to the selected model. The relationship used in this study is:

$$\log (Q_I) = \log (A) + B \log (Q_{DM}) \qquad (1)$$

where:

Q_I = instantaneous base flow at partial-record station;

Q_{DM} = daily mean base flow at a nearby continuous record station;

A = regression constant (intercept discharge when plotted on a log-log scale);

B = regression coefficient (slope).

The regression equation affords a means of estimating specific values of the dependent variable (ordinate) for a given value of the independent variable (abscissa). In this application, the average base flow during 1968-75 at the continuous-record station was used with the regression equation to estimate the average base flow at a nearby partial-record station for the same period. For the example in figure 4B, the average base flow of Carlls River (20.5 ft^3/s) is used to estimate the average base flow of Sampawams Creek for the same period (8.14 ft^3/s). Standard statistical procedures were adapted from Bhattacharyya and Johnson (1977) and Riggs (1968); these provide an estimate of the level of confidence in the predicted values as well.

Regression analyses for the 20 partial-record stations within the study area are presented in figure 5 (at end of report). The predicted mean base flow at these stations and the 95-percent confidence interval are presented in table 3.

Data for the streams with only partial records (fig. 5) were plotted against concurrent flows of two to four nearby streams having continuous records. Only the continuous-record stations that related most closely to the partial-record station are presented. More than 90 percent of the relationships attempted provided acceptable results; the only partial-record station for which no acceptable relationship was found was Seaford Creek in southern Nassau County. Criteria for determining the acceptance of an analysis and possible reasons for error are discussed in the following section, "Measures of Error." Unacceptable relationships are not presented in this report.

The sum of the average base flows of the nine streams having a continuous record is 90 ft^3/s (see table 4, p. 16). The sum of the estimated average base flows of the 20 streams with only a partial record was 73 ft^3/s (from table 3) with a 95-percent confidence interval of 63 to 84 ft^3/s. The total is 163 ft^3/s, which constitutes the ground-water seepage to streams from a ground-water drainage area that extends to the mid-island ground-water divide and receives 650 ft^3/s as recharge from precipitation (as estimated from average recharge rates). Even though the total ground-water seepage to streams included in this estimate does not include all streams nor those reaches below the gage, it still represents more than 25 percent of the recharge in the study area.

Table 3.--Predicted average base flow at low-flow partial-record stations, 1968-75.

[All discharge values are in cubic feet per second; stream locations are shown in fig. 1]

Stream name (dependent variable vs. independent variable)	Number of data points	Regression coefficient B	Significance of slope t (percent)	Standard error		Predicted base flow with 95-percent confidence interval	Average predicted base flow[1]
				Estimate (log units)	Prediction[2] (percent)		
Motts Creek							0.52
vs. Pines Brook	9	0.50	3.47 (>98)	0.1354	11.3	0.51 (.39, .66)	
vs. East Meadow Brook	11	1.45	5.41 (>99)	.1425	10.6	.53 (.42, .67)	
South Pond							.28
vs. East Meadow Brook	27	1.10	4.43 (>99)	.4369	30.8	.28 (.17, .45)	
Parsonage Creek							2.41
vs. Massapequa Creek	13	.78	3.31 (>99)	.1146	7.78	2.41 (2.04, 2.85)	
Milburn Creek							6.92
vs. East Meadow Brook	25	.22	4.27 (>99)	.0732	3.78	7.25 (6.71, 7.84)	
vs. Massapequa Creek	19	.31	3.85 (>99)	.0513	2.89	6.59 (6.20, 7.00)	
Cedar Swamp Creek							6.17
vs. East Meadow Brook	22	.79	7.91 (>99)	.1052	5.40	6.56 (5.87, 7.33)	
vs. Massapequa Creek	16	1.43	8.28 (>99)	.0886	5.12	5.77 (5.18, 6.43)	
Newbridge Creek							.60
vs. Massapequa Creek	16	1.43	2.57 (>97)	.3573	26.1	.60 (.38, .96)	
Seamans Creek							3.20
vs. East Meadow Brook	16	.71	6.06 (>99)	.1289	7.72	3.48 (2.96, 4.09)	
vs. Massapequa Creek	13	1.55	5.91 (>99)	.1295	8.48	2.92 (2.43, 3.50)	
Carman Creek							4.87
vs. East Meadow Brook	16	.37	3.33 (>99)	.1151	8.04	4.97 (4.20, 5.89)	
vs. Carlls River	16	.71	3.96 (>99)	.1058	6.69	4.76 (4.13, 5.48)	
Amityville Creek							2.66
vs. Carlls River	25	1.05	7.87 (>99)	.0986	4.78	2.68 (2.36, 3.04)	
vs. Sampawams Creek	24	.83	8.31 (>99)	.0926	4.50	2.68 (2.44, 2.94)	
vs. Penataquit Creek	25	1.05	5.49 (>99)	.1316	6.20	2.63 (2.32, 2.98)	
Great Neck Creek							2.10
vs. Penataquit Creek	4	1.15	2.32 (>85)	.0504	13.6	2.15 (1.20, 3.84)	
vs. Connetquot River	4	1.43	2.61 (>85)	.0461	10.6	2.04 (1.30, 3.21)	
Strongs Creek							1.60
vs. Carlls River	15	.50	6.60 (>99)	.0502	3.21	1.62 (1.51, 1.74)	
vs. Sampawams Creek	15	.40	5.96 (>99)	.0542	3.35	1.58 (1.47, 1.70)	
vs. Penataquit Creek	15	.69	5.17 (>99)	.0599	3.89	1.62 (1.49, 1.76)	
vs. Connetquot Creek	13	.75	5.30 (>99)	.0535	3.75	1.56 (1.44, 1.69)	
Neguntatogue Creek							3.34
vs. Sampawams Creek	19	0.53	4.21 (>99)	0.1018	5.51	3.33 (2.96, 3.73)	
vs. Carlls River	19	.59	3.81 (>99)	.1069	5.87	3.53 (2.97, 3.78)	
Santapogue Creek							7.95
vs. Carlls River	10	.74	9.09 (>99)	.0407	3.30	7.64 (7.08, 8.24)	
vs. Penataquit Creek	10	1.04	3.99 (>99)	.0792	7.18	8.26 (7.01, 9.73)	
Cascade Lakes Outlet							2.01
vs. Sampawams Creek	20	1.32	4.51 (>99)	.2533	14.2	1.94 (1.48, 2.55)	
vs. Penataquit Creek	20	1.83	4.74 (>99)	.2465	13.9	2.08 (1.59, 2.72)	
Awixa Creek							1.27
vs. Penataquit Creek	24	1.71	5.84 (>99)	.1995	9.89	1.28 (1.05, 1.55)	
vs. Connetquot Creek	21	2.27	4.34 (>99)	.2304	12.5	1.26 (.99, 1.61)	
Orowoc Creek							5.32
vs. Carlls River	5	.78	2.25 (>85)	.0569	7.59	5.31 (4.18, 6.75)	
vs. Penataquit Creek	5	.84	2.45 (>90)	.0539	6.61	5.17 (4.19, 6.38)	
vs. Connetquot Creek	5	1.50	3.19 (>95)	.0445	6.21	5.45 (4.48, 6.64)	
Pardees Pond Outlet							3.58
vs. Connetquot Creek	13	3.93	3.56 (>99)	.2527	20.4	3.58 (2.37, 5.40)	

Table 3.--Predicted average base flow at low-flow partial-record stations, 1968-75.--continued

[All discharge values are in cubic feet per second; stream locations are shown in fig. 1]

Stream name (dependent variable vs. independent variable)	Number of data points	Regression coefficient B	Significance of slope t (percent)	Standard error: Estimate (log units)	Standard error: Prediction[2] (percent)	Predicted base flow with 95-percent confidence interval	Average predicted base flow[1]
Champlin Creek							5.97
vs. Connetquot Creek	36	1.40	11.9 (>99)	.0628	2.62	5.81 (5.51, 6.12)	
vs. Carlls River	42	.91	11.8 (>99)	.0690	2.43	6.12 (5.83, 6.42)	
West Brook							3.73
vs. Connetquot Creek	7	1.49	3.77 (>98)	.0847	8.93	3.56 (2.84, 4.47)	
vs. Sampawams Creek	7	.86	2.59 (>95)	.1088	14.2	3.90 (2.72, 5.59)	
Rattlesnake Brook							8.80
vs. Connetquot Creek	23	.61	4.04 (>99)	.0678	3.31	8.67 (8.10, 9.28)	
vs. Carlls River	25	.43	5.25 (>99)	.0603	2.92	8.78 (8.27, 9.32)	
vs. Sampawams Creek	24	.37	4.83 (>99)	.0630	3.19	8.94 (8.37, 9.55)	

[1] average of regression estimates where more than one was available.
[2] standard error of prediction of average values.

Measures of Error

The reliability of the regression analyses presented herein is evaluated by two criteria. The first is the standard error of estimate (SEE), which is the standard deviation of the residuals about the line of regression; it is by definition a constant for a given analysis. SEE gives a general indication of the reliability of a regression. For this study, regression analyses were considered unacceptable if their SEE was greater than 0.5 log units.

The SEE of the example in figure 4B (Carlls River vs. Sampawams Creek) is 0.0847 log units, which means that approximately two-thirds of the observations should lie within 0.0847 log units of the regression line. The band showing this range about the regression line is included in figure 4B. The highest SEE for the 41 regression analyses presented in figure 5 and table 3 is 0.4369 log units, and all but two analyses had a SEE of less than 0.26 log units.

The second criterion for evaluation of the success of a regression analysis is a t-test of the significance of the regression coefficient (B), the slope of the regression line. If B = 0, it can be assumed that no linear relationship exists between the variables. That is, the relationship between the variables is either nonlinear or does not exist; an examination of the residuals will usually help decide. Regression analyses were considered unsuccessful if the significance of the calculated regression coefficient was less than 85 percent.

The significance of the slope in figure 4B is greater than 99 percent. Results of the t-tests for the significance of B in the regression plots in figure 5 are given in table 3.

The standard error of prediction (prediction of the mean response of the dependent variable for a specified value of the independent variable) is the primary measure of the accuracy of predictions made in the regression analyses. The standard error of prediction (of an average value) and other pertinent statistics for all regression analyses are given in table 3. The standard error of prediction (SEP) was calculated from the following equation:

$$SEP = SEE \sqrt{\frac{1}{n} + \frac{(X_o - \bar{X})^2}{S_x{}^2}} \qquad (2)$$

where:

SEE = standard error of estimate

n = number of data points

$\bar{X}$ = sample mean of independent variable

X_o = specific value of independent variable used for the prediction (calculated mean base flow at a continuous-record station)

$S_x{}^2$ = sum of squared deviations from the mean = $\sum_{i=1}^{n} (X_i - \bar{X})^2$

The SEP contains both error from the estimate of the regression coefficient and the error of the mean. The SEP is directly proportional to the SEE; thus, it follows that an increase in SEE will cause an increased error in a prediction made from the regression equation. As seen in equation 2, SEP is sensitive to the number of data points (n) in the analysis and to the departure from the mean $(X_o - \bar{X})$. In this application, departure from the mean is the difference between the actual mean for the period studied and the mean of the data used to define the relationship.

An example of an SEP hyperbola is shown in figure 4B (Carlls River and Sampawams Creek). The SEP is small near $\bar{X}$ but increases as the given X_o departs from $\bar{X}$ and approaches the SEE outside the range of the observations. The measured average base flow of Carlls River (X_o) is 20.52 ft^3/s, and the mean of the discharge measurements used in the analysis $(\bar{X})$ is 20.97 ft^3/s. Because the difference between these values (the deviation from the mean) is small and the number of data points large (n = 82), the SEP is appropriately small, 2.2 percent.

The number of data points in the graphs in figure 5 ranges from 4 to 42. Relationships having few data points have a greater SEP; however, even predictions based on fewer than 10 data points seem reliable. Similarly, even where these sparse data represent only a part of the 1968-75 study period, the results seem reliable. This reliability can be explained by two reasons. First, 1968-75 was a period near hydrologic equilibrium, when base-flow fluctuations were small; therefore, the discharge characteristics of any part of the study period are typical of the entire period. The second reason is that, in most regressions, the available observations were close to the actual mean base flow, so that the departure from the mean generally was small, which is an additional benefit of predicting average base-flow values.

EVALUATION OF REGRESION ANALYSIS

An evaluation of the predictive accuracy of the regression technique was made by comparing the results with records of adjacent streams having a continuous discharge record for 1968-75. Instantaneous discharge measured during periods of base flow at a continuous-record station (dependent variable) was plotted against the concurrent daily mean discharge of the closest continuous-record station to the west (independent variable); this was done for all continuous-record stations in the area. The regression model used for these analyses is the same as for the previous analyses (eq. 1), except that, in this application, Q_I is also the instantaneous discharge at a continuous-record station.

By the same statistical procedures described previously, the mean measured 1968-75 base flow of each continuous-record station, used as the independent variable, was used to predict the mean base flow at a nearby continuous-record station, used as the dependent variable. The discharge data are plotted in figure 6 (at end of report). The predicted base-flow data and the 95-percent confidence interval and other pertinent statistics are given in table 4. All but one of these relationships were acceptable. The SEE's of the relationships were less than 0.15 log units; the significance of their slopes was each greater than 99 percent, and their SEP was each less than 5 percent.

Because the mean base flow of all continuous-record stations used in this evaluation is known, these analyses can be used as a control, and the predicted mean base flow can be compared to the measured value. The predicted values lie either within or very close to the calculated 95-percent confidence interval, which strongly supports the validity of the estimation technique.

Three of the eight regression analyses yielded the predicted mean base flow with a 95-percent confidence range, which, although close, does not include the mean measured base flow. However, an assumption made in applying the regression analysis is that values of the independent variable (measured values) are without error, even though a small degree of error is inherent in estimating daily mean discharge from a stage-discharge relationship, as was done here. This measurement error may in turn introduce additional, although probably minor, error that was not considered in the analysis.

Although the number of data points in the control analyses is greater than in analyses to predict mean base flow at partial-record stations (presented earlier), the close agreement between predicted and measured base-flow values demonstrates the applicability of this technique to the Long Island hydrologic regime.

The regression analysis between concurrent discharges of Pines Brook and Valley Stream (fig. 6-8) resulted in a SEE considerably higher than the other control analyses. The slope of the regression line (B) is 0.02, nearly flat (zero), and the significance of the regression coefficient is low; together these facts indicate virtually no functional relationship between base flow in the two streams.

Table 4.--Predicted and observed average base flow at continuous-record stations, 1968-75.

[All discharge values are in cubic feet per second; stream locations are shown in fig. 2]

Stream names (dependent vs. independent variables)	Number of data points	Regression coefficient (slope)	Significance of slope t (percent)	Standard error: Estimate (log units)	Standard error: Prediction[2] (percent)	Predicted base flow with 95-percent confidence interval	Calculated average base flow[1]	Percent difference
Connetquot Creek vs. Penataquit Creek	33	0.72	6.26 (>99)	0.0749	3.0	33.2 (31.20, 35.22)	34.75	4.5
Penataquit Creek vs. Sampawams Creek	121	.44	9.53 (>99)	.0975	2.0	5.65 (5.43, 5.88)	5.92	4.6
Sampawams Creek vs. Carlls River	82	1.21	18.5 (>99)	.0847	2.2	8.14 (7.79, 8.50)	8.51	4.3
Carlls River vs. Massapequa Creek	84	.51	13.3 (>99)	.0785	1.8	19.41 (18.71, 20.11)	20.52	5.4
Massapequa Creek vs. Bellmore Creek	83	.82	12.1 (>99)	.1495	3.89	6.88 (6.38, 7.42)	6.60	4.2
Bellmore Creek vs. East Meadow Brook	35	.56	7.21 (>99)	.1212	4.93	7.85 (7.11, 8.66)	7.49	4.8
East Meadow Brook vs. Pines Brook	49	.30	7.74 (>99)	.1375	4.61	6.68 (6.09, 7.33)	6.44	3.7
Pines Brook vs. Valley Stream	42	.02	0.15 (<50)	.3791	23.6	0.28 (.18, .45)	.25	12
Valley Stream		--				--	.12	

[1] calculated by applying a technique of base-flow separation analysis to the continuous streamflow hydrograph by Reynolds (1982).
[2] standard error of prediction of average values.

It should be noted that the SEP and the 95-percent confidence interval of this prediction for Pines Brook (table 4) also are much larger than those for the other control predictions. However, the predicted mean base flow of Pines Brook (0.28 ft^3/s) is still close to the measured mean (0.25 ft^3/s). To further investigate the lack of a relationship between the Pines Brook and Valley Stream data, a prediction was made in which the average base flow of Valley Stream (X_0) was assumed to be 1.0 ft^3/s rather than 0.12 ft^3/s (fig. 6-8). The resulting predicted average base flow of Pines Brook was 0.30 ft^3/s (with 95-percent confidence interval of 0.20 to 0.43 ft^3/s), which is also close to the measured value. This demonstrates that, if the slope is near zero, there is no functional relationship between the discharge data, and that predictions are insensitive to the value of X_0. It follows then that the reason the predictions remain close to the measured value is that the mean of the discharge measurements on Pines Brook (0.29 ft^3/s) is close to the actual mean base flow during the period, and, if a different sample of base-flow measurements were used to develop the relationship, the predicted mean base flow could be much different from the actual value.

The Pines Brook and Valley Stream basins are more urbanized than the other stream basins in the study area (Simmons and Reynolds, 1982). In Valley Stream, total streamflow decreased from an average of 6.56 ft^3/s in 1955-61 to 1.05 ft^3/s in 1968-75, and in Pines Brook from 2.54 ft^3/s to 1.48 ft^3/s between the same periods. Base flow, expressed as a percentage of total flow, decreased from an estimated 95 percent under predevelopment conditions to 72 percent in Valley Stream and 73 percent in Pines Brook by 1955-61, then to 11 percent in Valley Stream and 17 percent in Pines Brook by 1968-75. Valley Stream could not be correlated successfully with partial-record stations in any regression analyses, and Pines Brook was successful in only one.

Reexamination of all regressions in this study indicates fewer acceptable relationships between pairs of Nassau County streams than between Suffolk streams, and correlation with continuous-record stations quite distant from the partial-record station proved necessary for some in Nassau County. This lack of agreement probably reflects the greater degree of urbanization and the greater variability in the local hydrologic conditions in southern Nassau County than in Suffolk County.

In many places on Long Island, construction has altered or constricted stream beds, which has changed the rate of ground-water seepage to the stream. Local stresses such as pumping for dewatering or other uses also lower water levels near streams and thereby alter the relationship of base flows among nearby streams. Recharge from precipitation, which under predevelopment conditions entered the ground-water reservoir uniformly, now enters in large volumes at recharge basins that collect overland runoff or from leaking sewers and water-supply lines.

In general, urbanization has disrupted the uniformity of seasonal and other natural fluctuations in the hydrologic system. The effects of urbanization on streams in the eastern part of the island are less significant than in the west, as reflected in the greater scatter of data among stream correlations in the west.

PHYSICAL SIGNIFICANCE OF REGRESSION ANALYSIS

Correlation of various discharge statistics among streams of similar hydrologic character has been done on streams throughout the United States. The relationship among concurrent low-flow discharges of streams near or adjacent to one another, as indicated in the relationships presented herein, results from the similarity of hydraulic characteristics that determine ground-water seepage to the stream channels and a similarity in the natural and man-induced hydrologic fluctuations that occur.

Streams draining to the south shore of Long Island would seem to be well suited for low-flow correlation because:

1. they have similar basin and channel characteristics,

2. the uppermost saturated geologic deposits have uniform hydraulic characteristics, and

3. the surficial material has high infiltration rates and low overland runoff, so that a large percentage of total annual streamflow is base flow.

As described in an earlier section, stream channels on Long Island act as ground-water drains in which the quantity of seepage changes with water levels near the stream. The simplest approach to quantifying base-flow seepage rates is to use the conductance form of Darcy's Law of ground-water flow:

$$Q_s = C\,(\Delta h) \tag{3}$$

where:

Q_s = quantity of ground-water seepage,

Δh = difference in head between average head in the aquifer and the average stream-channel altitude,

C = hydraulic conductance $= \dfrac{KA}{l}$,

K = average hydraulic conductivity along the path of flow from aquifer to stream channel,

A = cross-sectional area of flow, and

l = length of flow path.

The hydraulic conductance (C) is actually a "lumped parameter" that includes the hydraulic conductance of the streambed and the surrounding aquifer and must account for the complicated hydraulic geometry controlling seepage to the stream. A more detailed discussion of the mechanics of seepage to streams can be found in Reilly and others (1983).

Expressing the net ground-water seepage, or base flow, of two adjacent streams with equation (4), we obtain:

$$Q_1 = C_1 \Delta h_1 \tag{4}$$

$$Q_2 = C_2 \Delta h_2 \tag{5}$$

Assuming that adjacent streams experience similar hydrologic fluctuations and therefore similar ground-water-level fluctuations (that is, let $\Delta h_1 = \Delta h_2$) and substitute, we obtain the equation:

$$Q_1 = \frac{C_2}{C_1} Q_2 \tag{6}$$

This equation demonstrates a simple functional relationship between the base flow of the two streams.

Solving equation (1) for Q_I provides an exponential equation expressing the relationship between the untransformed data Q_I and Q_{DM}:

$$Q_I = A(Q_{DM})^B \tag{7}$$

This equation is the same as equation (6), given that B equals 1. It further indicates that for relationships with an exponent of unity, the regression constant (A) is related to the ratio of the hydraulic conductances that control ground-water seepage to the two streams considered.

In discussing the physical significance of the regression coefficient, Riggs (1972, p. 10) states:

> Ordinarily those relations having close to unit slope will be better defined and produce better estimates of low flow characteristics than relations having other slopes, because a unit slope relation indicates that the two streams have similar flow characteristics.

The regression coefficients of the 41 analyses used to predict the average base flow at partial-record streams ranged from 0.22 to 3.93; however, all but four ranged from 0.40 to 1.83. The mean of the calculated regression coefficients is 1.03; their standard deviation is 0.66. It was noted that six of the seven analyses with the largest standard errors of estimate had slopes greater than 1.3; however, no other relationship was evident between deviation from unit slope and the quality of the regression.

In view of the varied geometry of stream channels, local variations in hydrologic coefficients, and the complex three-dimensional distribution of head in the surrounding aquifer, this treatment greatly oversimplifies the mechanics of ground-water seepage to streams. Therefore, this relationship may be expected to depart from linearity as differences in stream profiles, stream length, and other hydrologic coefficients change and in turn alter the ratio of the hydraulic conductances of the streams. These complicating factors may require more complex expressions to define the discharge relationships between nearby streams. Nevertheless, this simplified approach is an aid in understanding the mechanics of base-flow relationships between adjacent streams and also indicates why the method is reliable for an area such as Long Island, where hydrologic variations in the shallow ground-water system are minimal, and streams consist predominantly of base flow.

SUMMARY AND CONCLUSIONS

Streams are part of the upper boundary of the Long Island ground-water system and are a major recipient of ground-water discharge; those in undisturbed areas derive as much as 95 percent of their total flow from ground-water seepage and significantly affect the configuration of the water table. Further urbanization on Long Island will affect ground-water levels, which in turn will reduce the base flow in many streams.

This report describes the application of a statistical technique to estimate average base flow at partial-record stations on Long Island, and defines the average base flow of the 29 major streams in southern Nassau and southwest Suffolk Counties during 1968-75.

The technique relates base flow at a stream with a partial-record station to concurrent flow in a nearby stream with a continuous-record station. A regression equation and the observed average base flow at the continuous-record station are used to estimate the average base flow at the partial-record station.

Average discharges and pertinent statistics for 20 partial-record stations are given. Each relationship had a standard error of estimate of less than 0.5 log units and a regression coefficient with greater than 85 percent significance. Most partial-record stations were correlated with several continuous-record stations, and base-flow estimates from each of these analyses show close agreement.

The only partial-record station for which no acceptable relation was developed was Seaford Creek in southern Nassau County. In general, Nassau County had more unacceptable relationships than Suffolk County, which most likely reflects the greater urbanization and heterogeneity of local hydrologic conditions in Nassau County.

Average base flow of the nine streams having a continuous record during 1968-75 totaled 90 ft^3/s, and the predicted average base flow for the 20 streams with only a partial-record was 73 ft^3/s (with a 95-percent confidence interval of 63 to 84 ft^3/s). The sum of the average base flows of the two groups--163 ft^3/s--represents a major part of ground-water seepage to streams in the study area and is more than 25 percent of all recharge in that area.

The close agreement among results indicates that this method can provide accurate estimates of average base flow in areas such as Long Island, where streams are hydrologically similar and consist largely of base flow.

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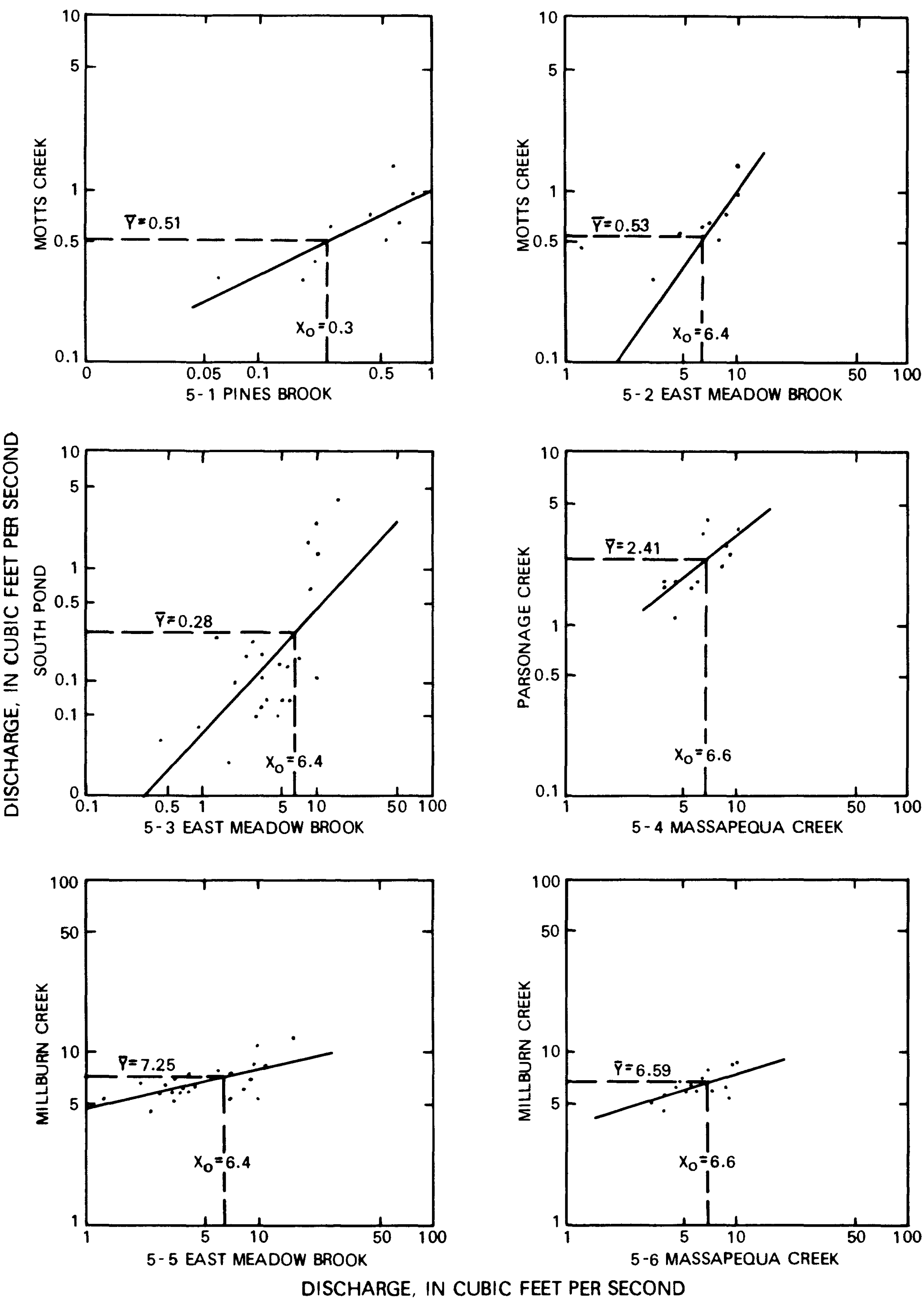
Figure 5.

Instantaneous base-flow discharge measured at partial-record station (ordinate) versus concurrent daily mean discharge at continuous-record station on a nearby stream (abscissa).

[Dashed line shows intersection of average measured base-flow discharge for 1968-75 at continuous-record station (X_O) and estimated average base flow at partial-record station ($\overline{Y}$). Estimated average base flows and statistics pertinent to the regression analysis are presented in table 3. Stream locations are shown in fig. 2 and described in tables 1 and 2.]

1. *Motts Creek vs. Pines Brook*
2. *Motts Creek vs. East Meadow Brook*
3. *South Pond vs. East Meadow Brook*
4. *Parsonage Creek vs. Massapequa Creek*
5. *Milburn Creek vs. East Meadow Brook*
6. *Milburn Creek vs. Massapequa Creek*
7. *Cedar Swamp Creek vs. East Meadow Brook*
8. *Cedar Swamp Creek vs. Massapequa Creek*
9. *Newbridge Creek vs. Massapequa Creek*
10. *Seamans Creek vs. East Meadow Brook*
11. *Seamans Creek vs. Massapequa Creek*
12. *Carman Creek vs. East Meadow Brook*
13. *Carman Creek vs. Carlls River*
14. *Amityville Creek vs. Carlls River*
15. *Amityville Creek vs. Sampawams Creek*
16. *Amityville Creek vs. Penataquit Creek*
17. *Great Neck Creek vs. Penataquit Creek*
18. *Great Neck Creek vs. Connetquot River*
19. *Strongs Creek vs. Carlls River*
20. *Strongs Creek vs. Sampawams Creek*
21. *Strongs Creek vs. Penataquit Creek*
22. *Strongs Creek vs. Connetquot Creek*
23. *Neguntatogue Creek vs. Sampawams Creek*
24. *Neguntatogue Creek vs. Carlls River*
25. *Santapogue Creek vs. Carlls River*
26. *Santapogue Creek vs. Penataquit Creek*
27. *Cascade Lakes Outlet vs. Sampawams Creek*
28. *Cascade Lakes Outlet vs. Penataquit Creek*
29. *Awixa Creek vs. Penataquit Creek*
30. *Awixa Creek vs. Connetquot Creek*
31. *Orowoc Creek vs. Carlls River*
32. *Orowoc Creek vs. Penataquit Creek*
33. *Orowoc Creek vs. Connetquot Creek*
34. *Pardees Pond Outlet vs. Connetquot Creek*
35. *Champlin Creek vs. Connetquot Creek*
36. *Champlin Creek vs. Carlls River*
37. *West Brook vs. Connetquot Creek*
38. *West Brook vs. Sampawams Creek*
39. *Rattlesnake Brook vs. Connetquot Creek*
40. *Rattlesnake Brook vs. Carlls River*
41. *Rattlesnake Brook vs. Sampawams Creek*


DISCHARGE, IN CUBIC FEET PER SECOND
MOTTS CREEK
Ȳ=0.51
X_O=0.3
5-1 PINES BROOK
MOTTS CREEK
Ȳ=0.53
X_O=6.4
5-2 EAST MEADOW BROOK
SOUTH POND
Ȳ=0.28
X_O=6.4
5-3 EAST MEADOW BROOK
PARSONAGE CREEK
Ȳ=2.41
X_O=6.6
5-4 MASSAPEQUA CREEK
MILLBURN CREEK
Ȳ=7.25
X_O=6.4
5-5 EAST MEADOW BROOK
MILLBURN CREEK
Ȳ=6.59
X_O=6.6
5-6 MASSAPEQUA CREEK
DISCHARGE, IN CUBIC FEET PER SECOND

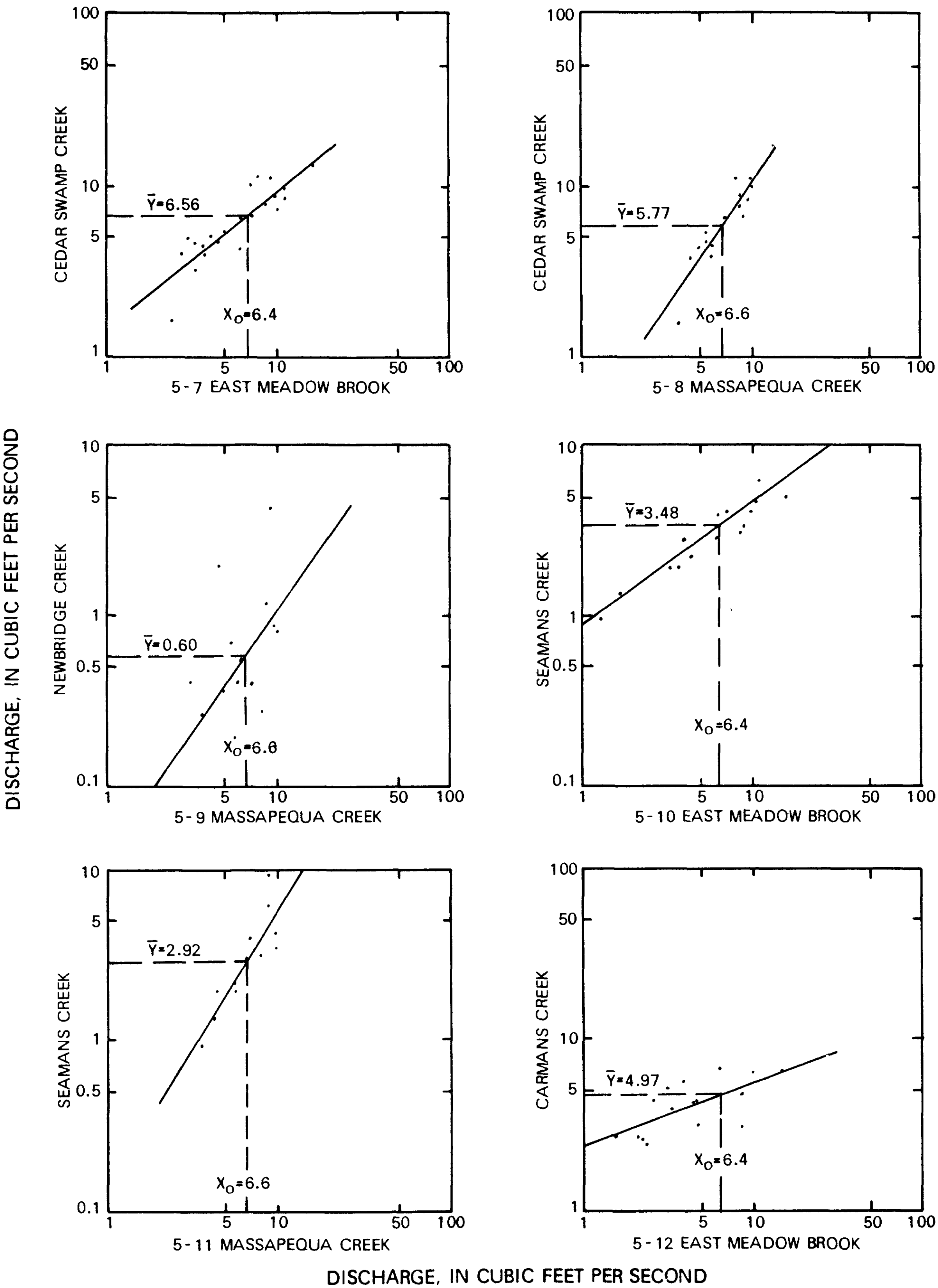


Figure 5 (continued)

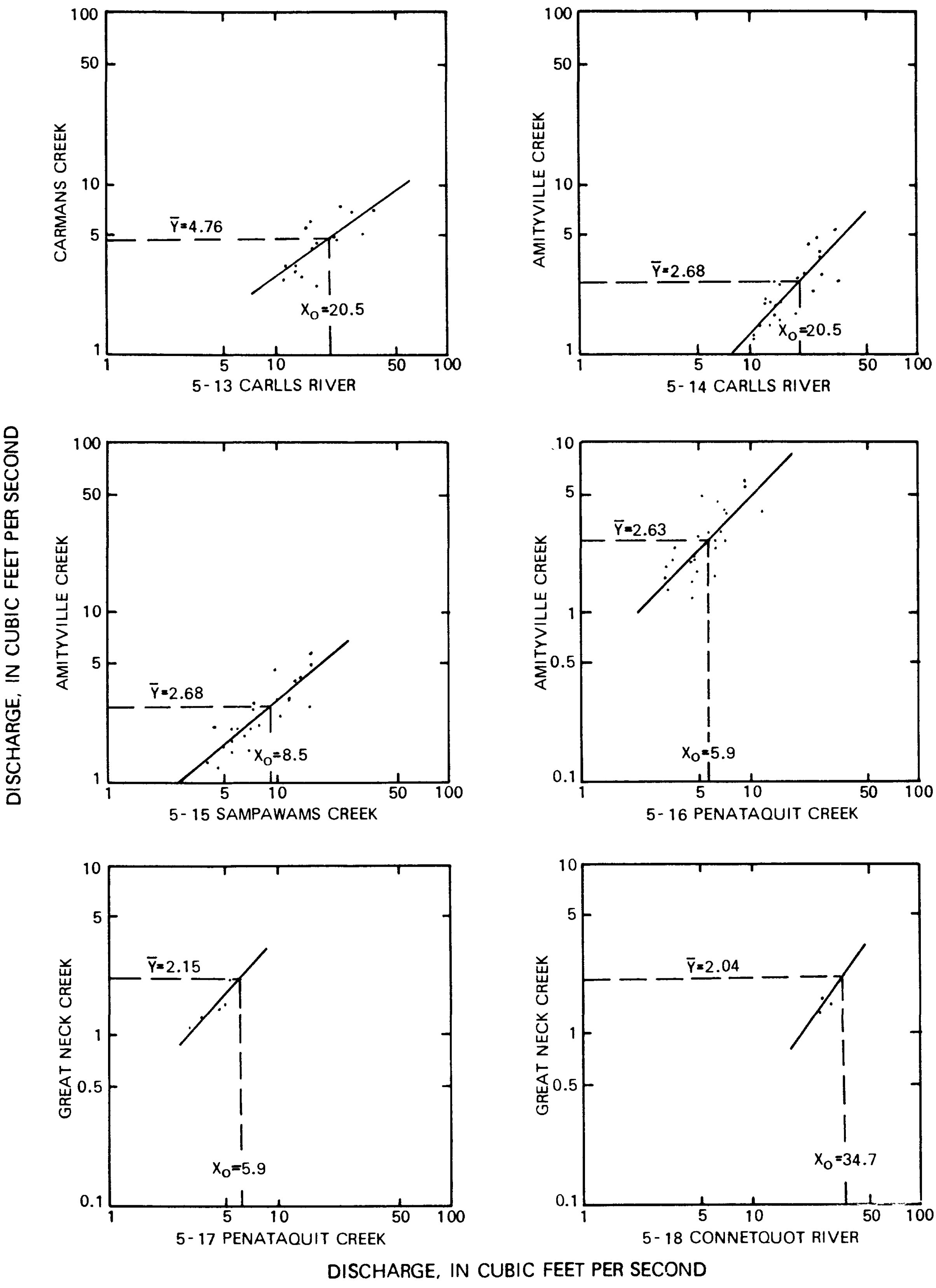
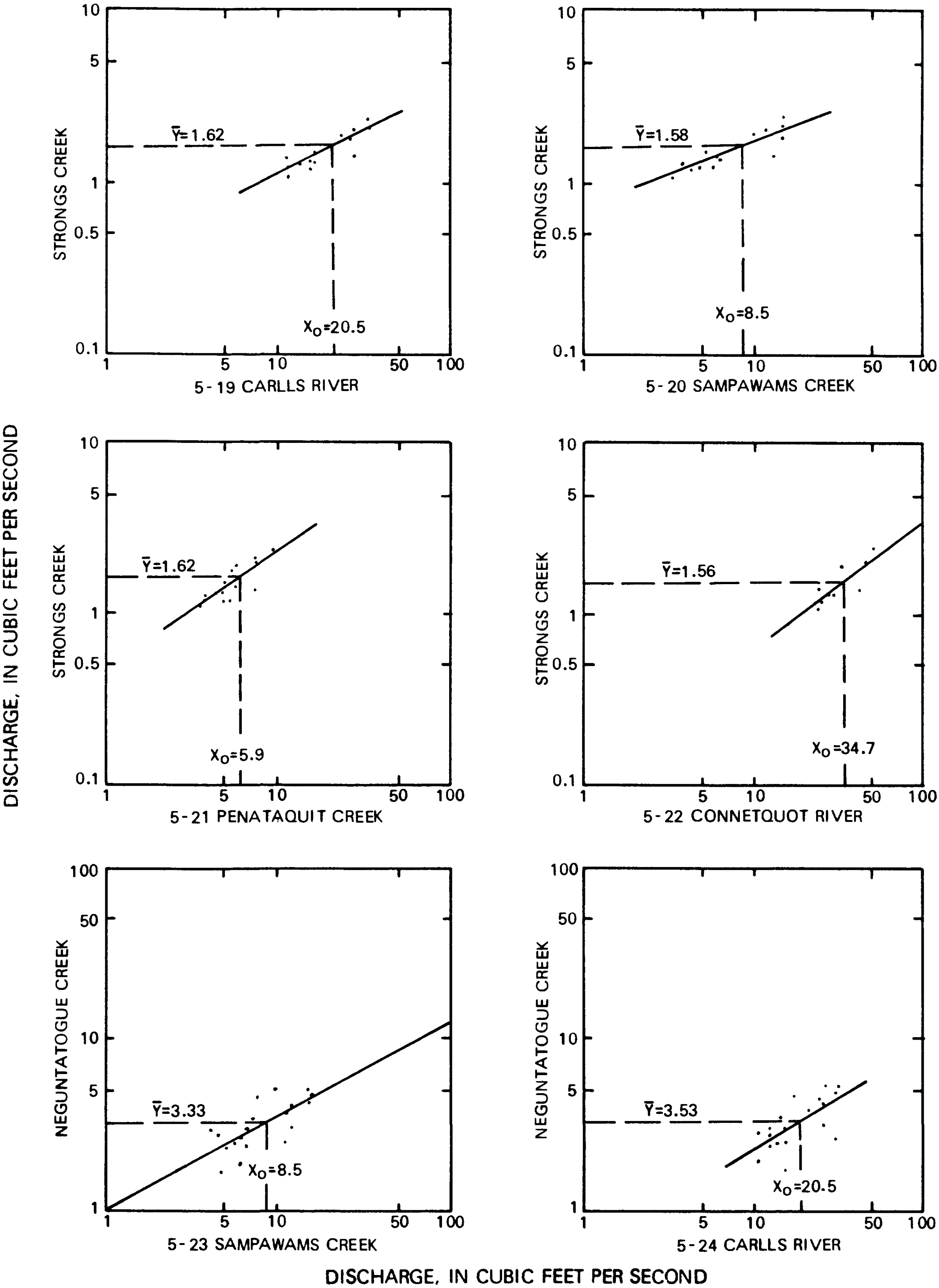


Figure 5 (continued)



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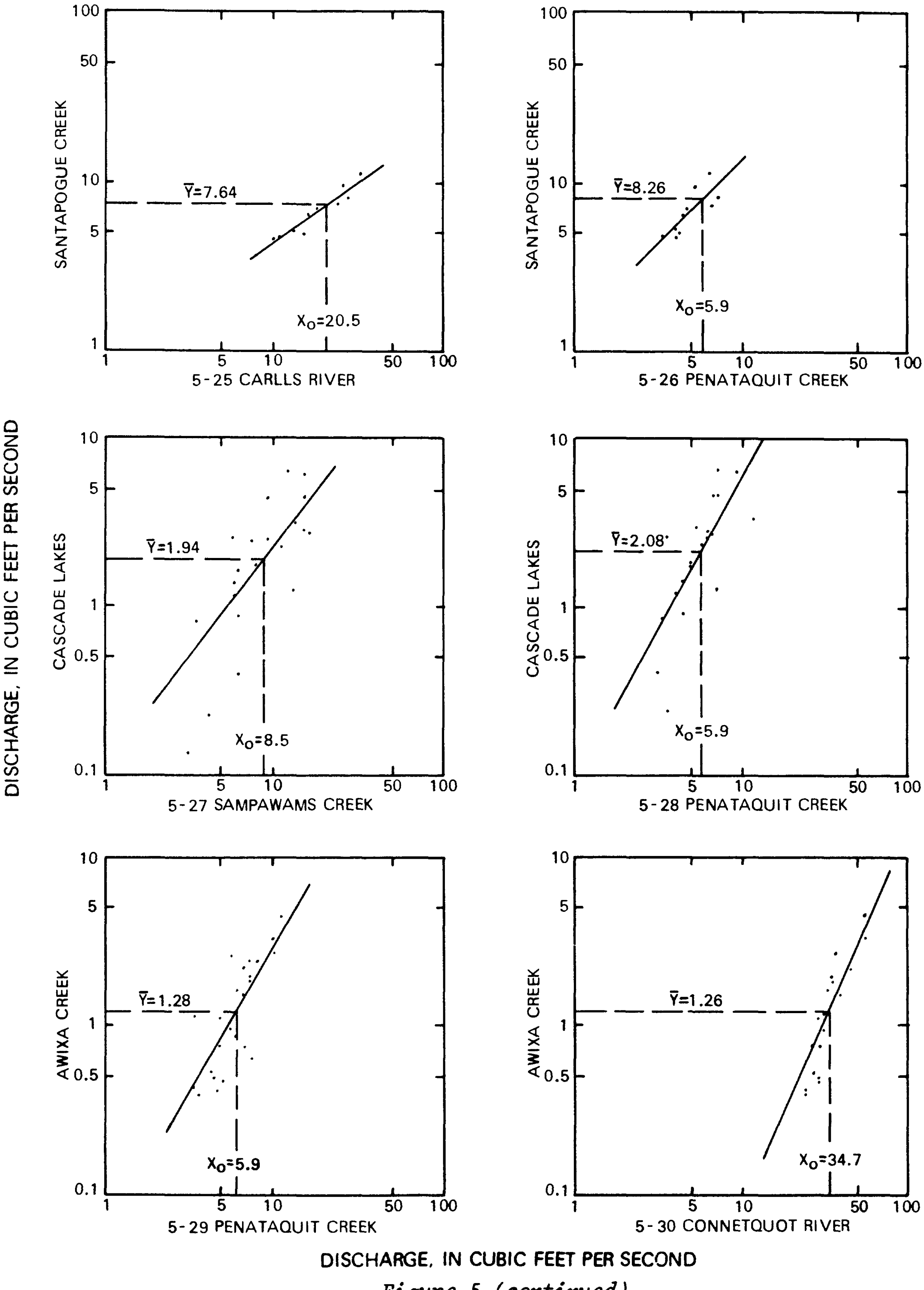


Figure 5 (continued)

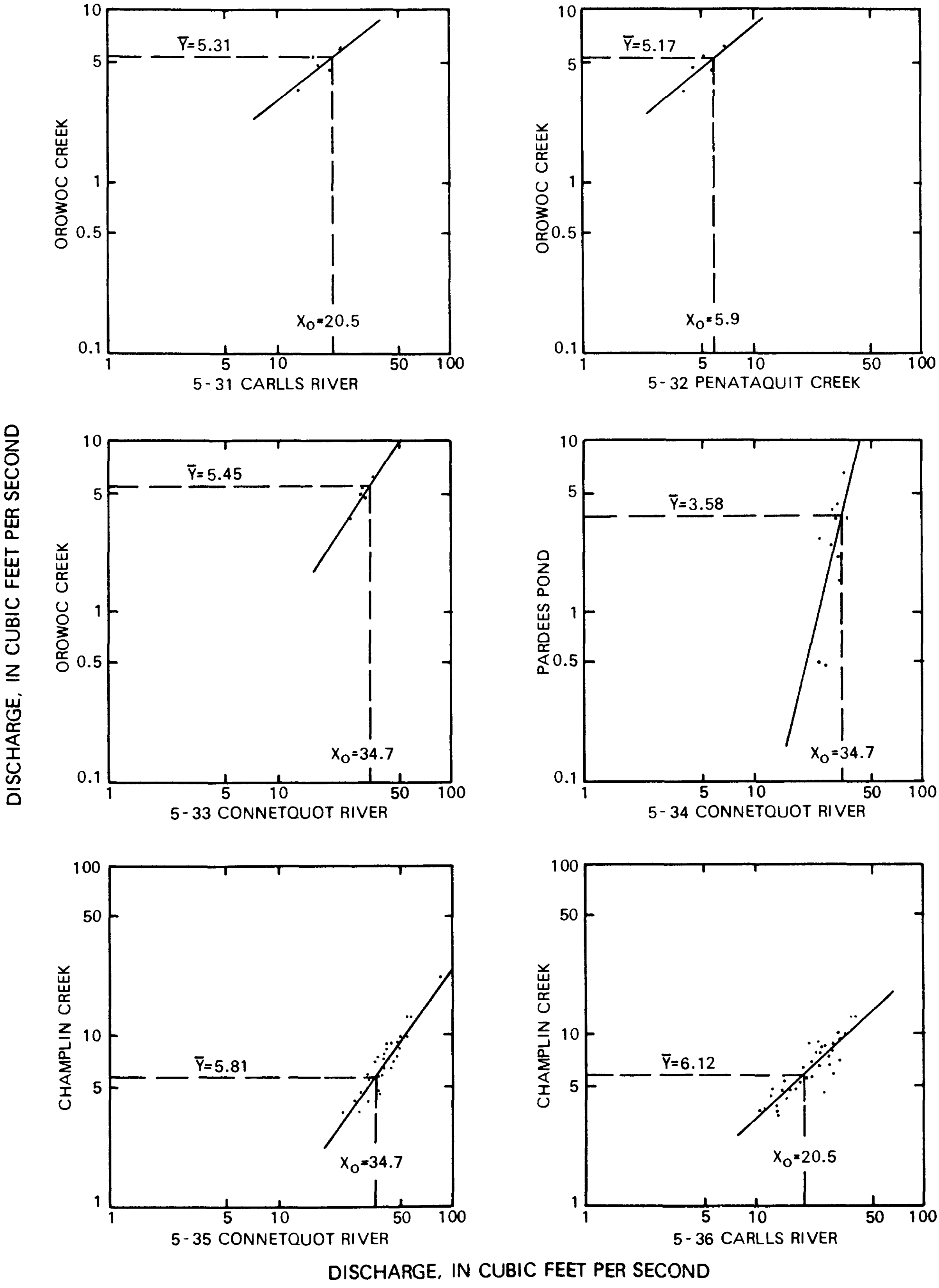


Figure 5 (continued)

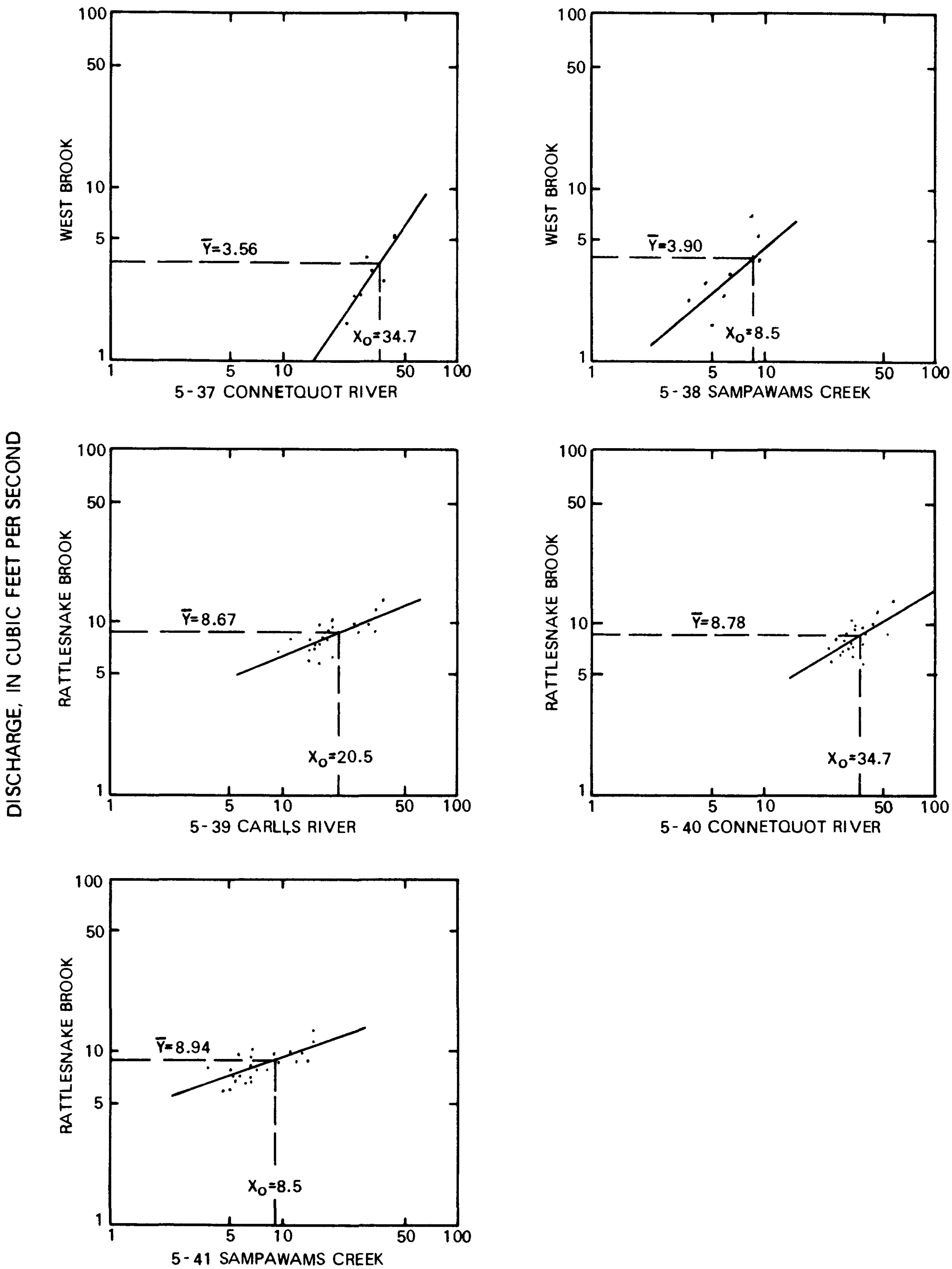
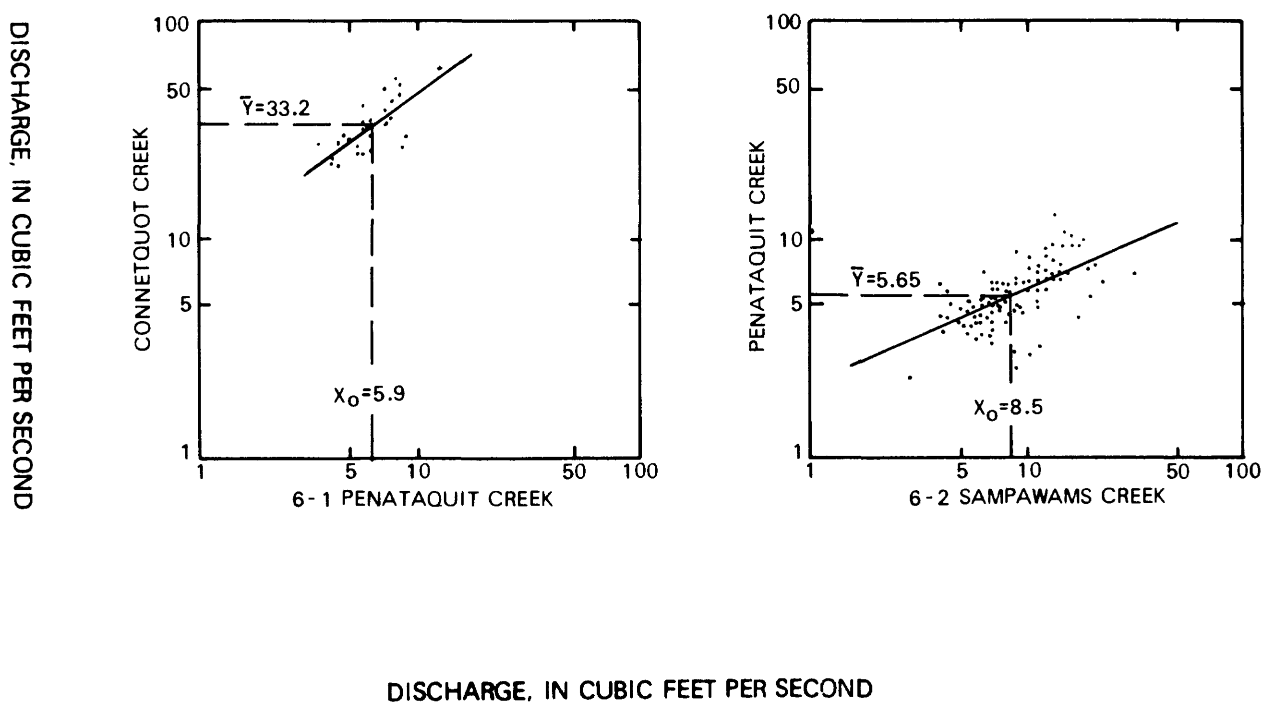


Figure 5 (continued)

Figure 6.

Instantaneous base-flow discharge at continuous-record station (ordinate) versus concurrent daily mean discharge at continuous-record station on a nearby stream (abscissa). Dashed line shows intersection of average measured base-flow discharge for 1968-75 at these stations (abscissa) and the estimated average base flow for the nearby station (ordinate). Estimated average base flow and statistics pertinent to the regression analysis are presented in table 3. Stream locations are shown in figure 2 and are described in table 1).

1. *Connetquot Creek vs. Penataquit Creek*
2. *Penataquit Creek vs. Sampawams Creek*
3. *Sampawams Creek vs. Carlls River*
4. *Carlls River vs. Massapequa Creek*
5. *Massapequa Creek vs. Bellmore Creek*
6. *Bellmore Creek vs. East Meadow Brook*
7. *East Meadow Brook vs. Pines Brook*
8. *Pines Brook vs. Valley Stream*
9. *Valley Stream*



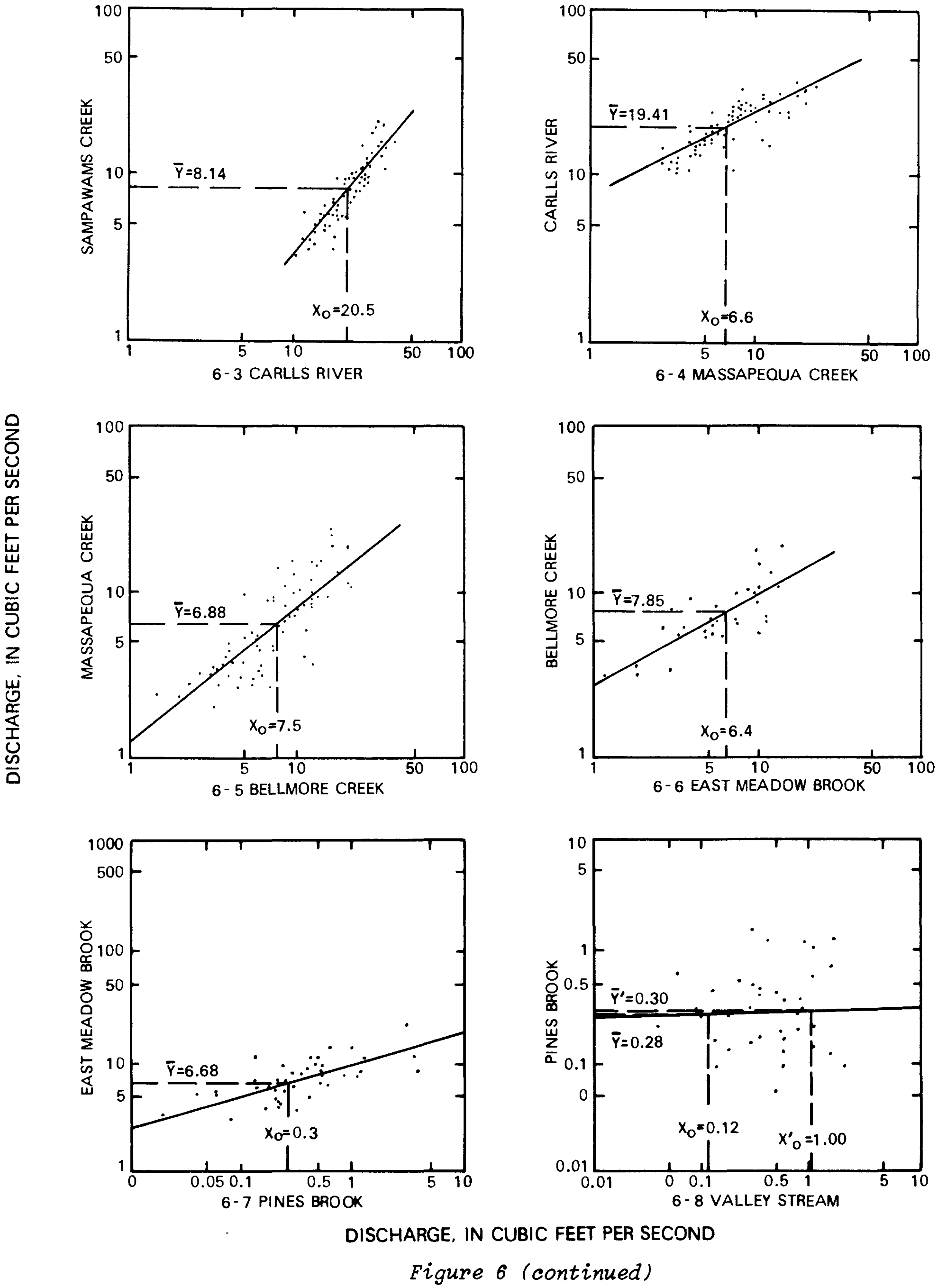


Figure 6 (continued)